2010 Astrobiology Survey of Springs in the North Anatolian Fault Zone: Windows into the deep terrestrial biosphere

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View of serpentinite slope to the left, along Adipazari-Mudurnu Rd. (D-140) approaching Taskeşti, Turkey.

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Introduction:

Numerous fault-controlled springs with unique geologic and chemical settings exist due to continuous tectonic activity in northwest Turkey. These springs represent the surface expressions of deeply-sourced subsurface chemical habitats and may provide insight into both terrestrial and extraterrestrial microbial communities. Reactions between deeply sourced fluids and mantle rocks exposed at the surface produce unique chemical conditions and potential habitats for subsurface microorganisms unique from microbes in surface environments. Due to the high content of ultramafic minerals in the region, serpentinization of mantle rocks and the production of hydrogen gas is of particular interest in this survey; springs located in serpentinite units were observed in region surrounding Taskeşti, Turkey, where a block of ancient mantle rocks has been uplifted from tectonic stresses. The dominant geologic features are within the North Anatolian Fault Zone (NAFZ) (Fig. 1), with numerous splay faults running perpendicular to the main fault, which runs northwest to southeast along the northern boundary of the Anatolian block. The objective of this survey was to assess the distribution of these springs and the surrounding geology and surface aqueous chemistry to infer the chemical conditions in the deep biosphere. Further interest stems from analogous fault-associated fluid seeps on Mars and the potential to relate our findings to extraterrestrial ecosystems and microbial life within these systems (Ehlmann et. al., 2010).

Geology of the North Anatolian Fault Zone:

During the Late Miocene to Pliocene eras, the North Anatolian Fault (NAF) resulted from the collision of the Arabian and Eurasian plates in present-day eastern Turkey and the closure of the ancient Tethys ocean (Neugebauer, 1995)(Fig. 1). The NAF represents the northern boundary of the Anatolian block, which is being pushed westwards as the Arabian and Eurasian plates collide (Neugebauer, 1995). The result of these tectonics is the development of convergent margins and an extensive strike-slip fault (the NAF), with numerous extensional oversteps and bends and normal faults parallel to the principal fault.

With the closure of the Tethys Ocean, it is likely that some of the ancient ocean waters and water incorporated in hydrated minerals (i.e. serpentinite) were captured in the suture zone defined by the NAF. Metamorphism from tectonic stresses would release water from hydrated minerals at depth; numerous artesian springs in this suture zone allow the escape of these deeply sourced waters. As the Anatolian block is pushed westward, fragmented mantle rock (mostly Peridotite) previously uplifted from the compressional stresses associated with the closure of the Tethyian ocean are exposed in the suture zone (Andrieux et. al., 1995). These rocks contain high amounts of magnesium, iron, as well as amphibolites, dunite and a variety of serpentinites. Fluid interaction with these ultramafic minerals produces hydrogen gas and serpentine minerals, increasing the alkalinity of the subsurface waters. Because of the great amount of pressure from tectonic stresses, surface upwellings from deeply-sourced springs are common, providing many windows into deep subsurface aqueous geochemistry.

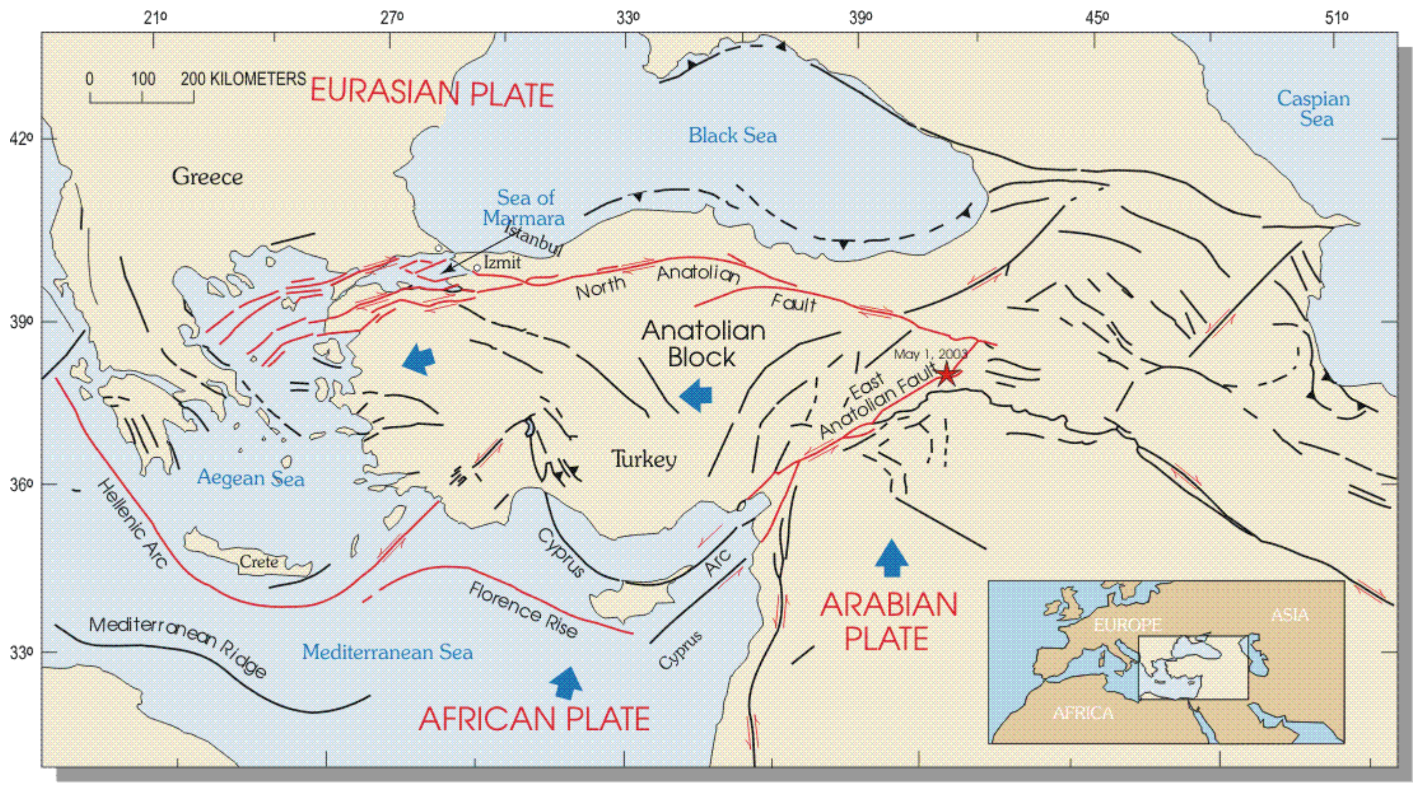

Figure 1: Diagram of tectonic movement in Turkey and the surrounding region. From the USGS National Earthquake Information Center (2003).

Also present in the region are Miocene age volcaniclastic layers exposed at local highs (Fig. 2). Iron oxides were also abundant within the sedimentary layers, observed as reddish conglomerate layers. Erosion after the closure of the Tethyian Ocean deposited layers of lake sediments and intercontinental red beds. For the purpose of this study, different host rocks of springs along the NAFZ were selected for *in situ* analysis of fluid, gas and mineral chemistry. Peridotite, pyroxenite and amphibolite host rocks were all observed in close proximity due to the complexity of the fault zone and the presence of olivine-rich mantle rock wedged in the suture zone. Both cold seeps and thermal springs were present in a variety of geologic formations, allowing for study of meteoric water-derived and deeply sourced fluids.

Figure 2: View of regional geology surrounding Taskeşti, Turkey. Local highs are predominantly volcanic deposits.

<u>Methods</u>:

To assess the geochemistry in deep subsurface ecosystems, artesian springs from several locations in northwest Turkey were sampled for biogeochemistry and microbiology, as well as analyzed for major chemical constituents. Samples were taken for RNA extractions and for culturing microbes that might inhabit such systems. The sites were chosen based on the local geology that differed across the NAFZ. Three thermal springs with temperatures ranging from 60 to 80 degrees Celsius were sampled; pH ranged from 6.6 to 8.4. Meteoric water likely diluted the subsurface spring waters, affecting chemical results. One cold spring seeping from the face of a serpentinite slope was also sampled; appreciable biofilm of a reddish orange color was observed and collected for RNA extraction and lab culturing. *In situ* spectrophotometry was performed at two of the thermal springs to provide preliminary chemical data (Kozu and Kuzuluk thermal springs). Major ions analyzed included: nitrite, nitrate, sulfide, sulfate, ammonia, silica, phosphate, chloride, total and ferrous iron, as well as dissolved oxygen. GPS coordinates were recorded for all sites visited in UTM units and will be used to create a map describing geospatial variations in biochemical conditions. Refer to Fig. 3 for a satellite image of the study region.

Figure 3: Google Earth image of study region. Study sites are marked with a yellow pin and reveal variations in spring sources and/or host rocks: Kuzuluk (Temp. 73-82°C, pH 6.66); Kozu-Taskesti (Temp. 62.3°C, pH 8.63); Dokurcun (Temp. 21.6°C, pH 8.22) and Sakarılıca (Temp. 49.4°C, pH 6.65).

<u>Results & Discussion</u>:

Several artesian wells were located along main roadways: Mihalgazi/Eskeşhir Rd. followed a southward transect through a peridotite complex, variably altered to serpentinite. As such these springs are of interest in serpentinization processes and alkaline habitats. Local wells at these sites provided local tap water from 150 meters depth. The pH was highest (8.31-8.36) in springs emanating from partially serpentinized dunite complexes. The temperature at the dunite cold springs is 18.5-18.9°C, however the subsurface water source is believed to be a peridotite complex. This study area, which had numerous tapped wells, is known as the Kupülüce complex, primarily composed of altered ultramafic mantle rock.

A. Sakarılıca Springs:

Further south, the local geology is predominantly amphibolites, with nearby faulting producing highly pressurized hot springs. Several springs nearby were tapped as wells and suitable for drinking, with pH values of 7.3 to 7.6 and temperatures between 14-17°C. Although the local geology surrounding these wells was predominantly serpentines, the quality of the water did not suggest novel microbes were present. Our attention shifted towards a nearby hot spring in the town of Sakarılıca.

Water from this thermal spring is pumped from a depth of approximately 150 meters and was collected for future laboratory analyses (i.e. RNA extraction, microorganism culturing). This water was slightly more acidic (pH of 6.32 at a temperature of 48.7°C) than cooler springs found at higher elevations. I obtained in situ chemical data for this spring on dissolved oxygen, phosphorus, ammonia, nitrate and total iron levels using our portable spectrophotometer. As expected dissolved oxygen and nitrate levels were low (0.2 mg/L and 0.6 mg/L respectively). Further chemical data will be obtained in the laboratory from local mineral and fluid samples collected to establish a chemical framework for the subsurface water source. Fluid from this source was also collected for inoculations and culturing at Dr. Meyer-Dombard's laboratory at the University of Illinois at Chicago.

B. Saricakaya springs:

Another fault-controlled spring downhill, closer to Saricakaya, had a pH value of 6.42 and a temperature of 28.7° C. Due to the rainy weather that day (June 25th, 2010), it is unclear if these values reflect the true subsurface source waters, as dilution with meteoric waters was almost certain. Further up Sakarıılıca -Eskişehir Rd., more cisterns were observed directly on serpentine and Peridotite slopes (pH of 7.45, temperature of 17°C). Higher pH values were observed in springs emanating out of the Kupülüce Complex, composed primarily of dunite (pH of 8.36, temperature of 18.9°C). This particular cistern was filled with green algae and also suitable for drinking. The presence of green algae suggests the surface waters were very suitable for microbes commonly found in freshwater ponds and active serpentinization at this location appeared unlikely. As such we shifted our attention to nearby thermal springs to the north and east.

C. Kuzuluk thermal spring:

The second thermal spring analyzed was at Kuzuluk thermal spa; temperature ranging from 73.6 to 82°C, with a pH of 6.66. The depth of the well was stated by local residents as approximately 190 meters. Thermal spring waters here had low dissolved oxygen levels (1.0 mg/L), ammonia and sulfide present (5.2 mg/L and 294 µg/L S^{-2}respectively), low chlorine levels (0.01 mg/L Cl_2) and significant water hardness. The hardness is believed to be due to hydroxide anions rather than carbonate hardness because no reaction between concentrated HCl and scale deposited on old piping was observable.

D. Serpentine cool seep, near Dokurcun:

Our next site was a cold seep flowing down a serpentinite slope, located off Dokurcun-Taskeşti Rd. Orange-colored, mossy biofilms were observed and collected for culturing in Dr. Meyer-Dombard's laboratory. Fluids were also sampled for gas chromatography analysis and DNA extraction (Fig. 4). Mineral samples were collected to provide culturing surfaces suitable for native microbes present. This site was the most biogeochemically interesting because I observed changes in biofilm growth on the exposed slope in the main channel of the seep versus biofilms extracted from a few centimeters beneath the surface (obtained by gently scraping off a small portion of the slope). The pH of these waters was 8.22 at a temperature of 21.6°C. The flow rate of the spring was too low to perform in situ spectrophotometry so fluid chemistry must be inferred from mineralogical and fluid analyses (performed by Dr. Cardace at NASA-Ames).

Figure 4: Sample collection of fluids seeping off a serpentinite slope near Taskeşti (pH = 8.22; temperature of 21.6°C).

E. Kozu thermal spring:

The final site was our third thermal spring located at Kozu thermal spa (pH = 8.5, temperature of 60°C). Fluids, gases, biofilms and mineral samples were all collected at this site. Approximately 40 liters of water were pumped through a filter for RNA extraction by Dr. Cardace as I analyzed the fluid chemistry with our spectrophotometer and Dr. Meyer-Dombard inoculated biofilms observed at the site for culturing and DNA extraction. Concentrations of dissolved oxygen, sulfide, total and ferrous iron, nitrate, nitrite, ammonia, chlorine, and phosphorus were all obtained via spectrophotometry. The local geology here is predominantly amphibolites. Numerous faults nearby have created springs from many geological units, including the serpentinite seep located along the same road.

Conclusions & Future Objectives:

Our lack of chemical data within the North Anatolian Fault Zone inhibits a complete understanding of the diverse geochemical habitats observed. Further laboratory work and data collection is essential to assess the microbial and chemical diversity of subsurface ecosystems. Future research goals include:

- Produce a map describing the locations and varying geochemical conditions of fault-controlled springs in the region will be produced in order to better assess our findings and determine an appropriate research plan for future projects.

- Compare microbial activity within spring fluids among different host rocks.

- Determine microbial diversity among sampled locations via lab cultures and DNA extraction, ensuring a close reproduction of environmental conditions in the deep subsurface biosphere by using collected samples for culturing media.

Given the high geologic diversity within the region, it is expected that microbial diversity may vary spatially as well. This project has provided us with only a glimpse of the life that lies deep below the surface of our planet, and potentially on other planets as well.

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